A11102 129004

NAT'L INST OF STANDARDS & TECH R.I.C.

A11102129004
/Bureau of Standards journal of research
QC1 .U52 V6;1931 C.1 NBS-PUB-C 1928

MEASUREMENTS OF EXTREME ULTRA-VIOLET SOLAR RADIATION USING A FILTER METHOD

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ABSTRACT

In this paper quantitative measurements are given of the component of ultra-violet solar radiation of wave lengths less than 313 mμ.

The method used is a type of filter radiometry, employing a nonselective thermocouple receiver, permanently covered with a filter that is highly transparent to short wave length ultra-violet radiation and practically opaque to the visible and the infra-red rays. By temporarily placing in the path of the rays first one, then two screens of barium flint glass which is opaque to wave lengths less than 313 mμ, the ultra-violet of wave lengths less than 313 mμ is evaluated by exclusion from the total ultra-violet measured.

Measurements are given of the incident ultra-violet solar radiation on the clearest days, as affected by atmospheric pollution, altitude of the station, humidity, time of the day, and season of the year. These data are discussed and correlated with some of the measurements and calculations made by others.

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I. INTRODUCTION

The present communication is a further contribution to the general subject of instruments and methods of radiometry, that has been under investigation for some years (1).[1] The particular problem considered, which is still under investigation, is the quantitative measurement of short wave length ultra-violet solar radiation.

The method of observation is by means of a nonselective radiometer, permanently covered with a filter that is highly transparent to the ultra-violet radiation of wave lengths less than 313 mμ (millimicrons, 3130 A) and opaque to practically all of the visible and the infra-red rays. Since this filter transmits ultra-violet of wave lengths longer than 313 mμ, the component of wave length less than 313 mμ, is evaluated by temporarily placing in the path of the incident rays, first one, then two screens of barium flint glass, which exclude these rays from the total ultra-violet measured. In this sense, it is an exclusion method of filter radiometry.

[1] Figures in parenthesis here and throughout the text indicate references given in the Bibliography at the end of this paper.

A pressing question of interest and far-reaching importance is a reliable method for evaluating the amount of ultra-violet radiation in sunlight of wave lengths less than about 313 mμ, which varies with the altitude and latitude of the station, the time of the day, the season of the year, cloudiness, and with the countless variations in atmospheric pollution by dust, smoke, etc., that are encountered in different localities.

This subject was discussed in a previous paper (2) in connection with the transparency of special window glasses for transmitting the short wave length ultra-violet solar radiation, of wave lengths less than about 313 mμ, recognized by biologists as having a specific healing value, particularly in the prevention and cure of rickets.

From the preliminary observations given in the preceding paper (2), it was evident that in order to be of value, measurements obtained by this method, should be made only during cloudless intervals. Such a procedure is not objectionable, and, since no other methods equally promising were available at that time it was decided to give the filter method a trial, extending over an annual cycle in order to include winter and summer weather, at Washington. Measurements were made also at two stations at Flagstaff, Ariz., in order to determine the effect of altitude and humidity.

The data thus obtained contain some interesting information that will be discussed on a subsequent page. In a future communication it is proposed to give similar data obtained by a modification of Method III, previously described (2) in which the thermocouple was covered with only a 1 cm cell of water (with quartz windows) and the ultra-violet radiation of wave lengths less than 313 mμ was excluded by means of a barium flint glass screen, as used in the present investigation.

The modification now under investigation consists in exposing both thermocouple receivers ("hot" and "cold," adjusted radiometrically closer than 1 per cent) to the sun, under which conditions practically no galvanometer deflection is obtained. By covering one thermocouple with the barium flint glass screen and the other receiver with a plate of Corex A glass or quartz (to compensate for reflection of radiation at 365 to 1,400 mμ) the galvanometer deflection, obtained on the simultaneous exposure of the two receivers to the sun, is a measure of the ultra-violet excluded by the flint glass filter. By interchanging the screens, differences in the two thermocouple receivers are eliminated.

The chief difficulty lies in obtaining two screens (one opaque to the ultra-violet and the other transparent to the ultra-violet, of wave lengths less than 313 mμ) having exactly the same transmission for wave lengths beginning at about 365 mμ and extending to about 1,400 mμ. Owing to the large amount of radiation in this spectral region, slight differences in the transmission may cause errors in the radiation measurements that are greater than the ultra-violet component that it is desired to measure.

By covering both receivers with a yellow, Noviol C, glass, differences in transparency of the barium flint glass and the Corex A or quartz screens, between 365 and 1,400 mμ, are determined and deducted from the ultra-violet at wave lengths less than 365 mμ excluded by the barium flint glass filter.

The energy value of the ultra-violet shut out by the filter may be determined directly by calibration of the thermocouple receiver

against a standard of radiation as in the previous measurements (2), or from the total solar intensity, Q (and the reduction factor F) as described in the present paper. The results obtained by this new method are in good agreement with the data given in the present paper, from which it appears that reliable results may be obtained by using only one barium flint glass screen. It is a good check on the present data by a widely different method.

If desired, this device can be connected with a recording apparatus, thus obtaining a continuous record as used by Pettit (9). However, owing to the large amount of radiation incident upon the water cell (1.2 g cal./cm^2/min. as compared with about 8 per cent of this value when using the herein described ultra-violet filter) care must be taken to avoid heating of the cell. In this respect the present method, in which the ultra-violet filter transmits over 80 per cent of the short wave length ultra-violet (without distortion of the shape of the solar spectral energy curve of wave lengths less than 350 mμ) but transmits only 8 per cent of the total solar intensity, Q, seems preferable. The ultra-violet filter is to be used also in the new method when it is not being used to check the present method.

With reference to the data presented in the present paper the measurements obtained in Washington are of particular interest in showing the seasonal variation in ultra-violet radiation that may be expected at a sea-level station which is not subjected to atmospheric pollution by factory smoke, but has to contend mainly with pollution by the combustion products from automobiles, and with the increasing numbers of incinerators and oil burners, in office buildings, apartment houses, and private dwellings, which emit not only smoke but also atomized particles of oil.

In this connection it is relevant to anticipate the discussion of the present observations by citing the measurements of October 8, 1929, when the northwest section of the city of Washington was enveloped in a rather dense low-lying stratum of finely divided particles that absorbed the short wave length ultra-violet rays. The atmosphere was cloudless and windstill, and the stratum of bluish haze was easily discernible, extending to a height of 500 to 1,000 feet. As the sun mounted higher in the sky, it shone through a decreasing thickness of this stratum, and the amount of ultra-violet transmitted was greatly increased. For example, the ultra-violet component measured at 9.15 a. m. was about two times the value measured 15 minutes earlier when the sun's rays traversed a longer path of smoke.

II. METHOD OF OBSERVATION

As outlined in a previous paper (2) the method used consists essentially in isolating the ultra-violet radiation by a purple glass filter, Corning G986A, which is highly transparent to ultra-violet radiation of wave lengths between 250 and 440 mμ (tr=80 to 81 per cent between 310 and 360 mμ) and measuring the intensity of the transmitted rays by means of a thermocouple (of copper-constantan, in air) having a receiving surface about 2.8 mm in diameter. A water cell of fused quartz, 1 cm in thickness, combined with the purple glass filter, G986A, absorbs all the infra-red rays of wave lengths longer than about 1,400 mμ. A correction is easily obtained for the small amount of infra-red rays, of wave lengths 700 to 1,400 mμ, transmitted by the glass filter.

The ultra-violet solar radiation of wave lengths 290 to 313 mμ is obtained by exclusion, by inserting a plate of barium flint glass (G669, thickness = 3.05 mm) having a transmission of 0.5 per cent at 313 mμ, 49 to 50 per cent at 334 mμ, 85 per cent at 365 mμ, and 90.7 per cent or a trifle higher throughout the visible and infra-red to 1,400 mμ and longer wave lengths. The long wave length limit of the ultra-violet cut-off is taken at (and including) 313 mμ instead of 310 mμ because it is a definite and easily obtained emission line (of the mercury arc spectrum) and, also, because biological action, at least in preventing rickets, terminates practically at this wave length (6).

The complete mounting, on its improvised polar axis, is shown in figure 1. The shutter, *S*, is shown opened to the left. The small aluminum disk, *D*, was used to shield the thermocouple receiver from the direct rays of the sun when measurements were made of the sky radiation. The notches in the diaphragmed opening show the compartments for the water cell and the filters.

The diaphragmed opening (19) was purposely constructed to admit radiation from a solid angle of 45° to the sky, which, by scattering, contributes (6 to 10 per cent or more, Table 2) ultra-violet radiation useful for therapeutic purposes. The whole metal box containing the thermocouple and diaphragmed top was wrapped in white cotton batting in order to provide a highly reflecting, thermally nonconducting medium, to reduce the heating on exposure to sunlight.

The experimental procedure consisted in exposing the copper-constantan thermocouple (permanently covered with the 1 cm cell of water and the purple glass, G986A) to the sun and noting the decrease in the galvanometer deflections when increasing amounts of ultra-violet radiation were shut out (*a*) by one filter, then (*b*) by two filters of barium flint glass, G669. The combination of two samples of glass is used to measure the ultra-violet spectral energy distribution in the region of 313 to 365 mμ, and gives some interesting information regarding the variation in energy in this spectral region, which variation is not necessarily in coincidence with the variation in ultra-violet of wave lengths less than 313 mμ shut out by the first screen.

As a matter of information it is relevant to add that in the Washington measurements an ironclad Thomson galvanometer was generally used; also a high sensitivity d'Arsonval galvanometer having a single swing of about seven seconds. At the Lowell Observatory, Flagstaff, Ariz. (altitude 7,250 feet), and on the San Francisco Peaks (near Flagstaff, altitude 10,500 feet) the greater solar intensity warmed the water cell so rapidly (thus affecting the thermocouple) that it was necessary to use a d'Arsonval galvanometer having a single swing of two to three seconds.

An Ångström pyrheliometer was used to measure the solar radiation intensities at the Flagstaff stations. For the Washington comparisons the solar radiation intensities were kindly supplied by I. F. Hand, of the United States Weather Bureau.

It is to be noted that measurements were made only on apparently cloudless days, or parts of days, when sky conditions remained uniform for an hour or more. By making 20 to 40 readings, in Washington, and about 10 readings at the Flagstaff stations, it was possible to attain an accuracy of 1 per cent or greater. The great variations

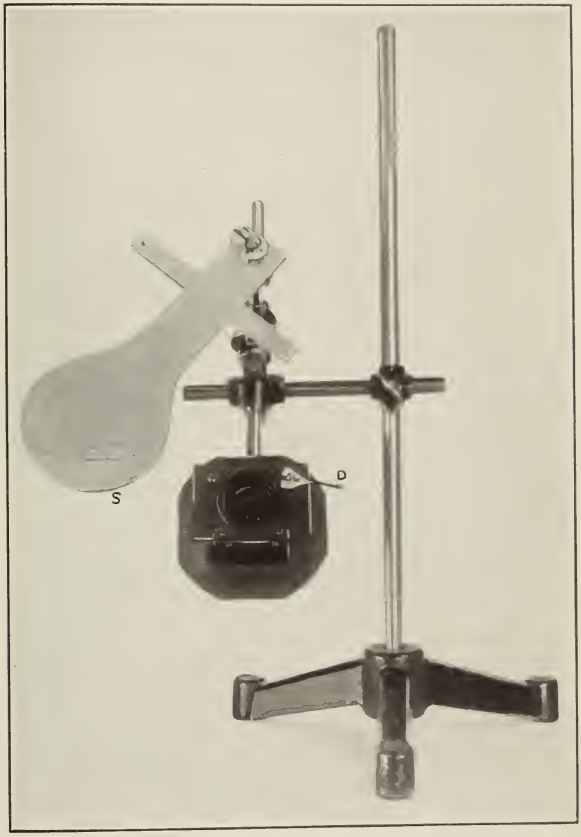

FIGURE 1.—*Front view of ultra-violet radiometer*

The notches in the diaphragmed opening show the compartments for the filters.

in the measurements are, therefore, to be ascribed to atmospheric conditions, which (at sea level) are never stationary as regards transmission of ultra-violet radiation, however uniform the sky may appear to the eye.

This is easily observed with a photo-electric cell that is sensitive only to ultra-violet radiation of wave lengths less than 313 mμ. From their experience with quick-acting photo-electric cells which respond to slight changes in atmospheric transparency, the writers have found it extremely difficult to obtain accurate measurements of the ultra-violet in direct sunlight. This unsteadiness is scarcely noticeable when measuring, with a photo-electric cell, the ultra-violet radiation from wide expanses of the sky. The reasons for these great variations become apparent in going from a low to a high elevation, where the observer becomes aware of the narrow range that obtains in the equilibrium conditions of the temperature and the pressure of the air (at least at certain seasons of the year) as indicated by the sudden appearance, and equally sudden disappearance, of small diaphanous clouds in an otherwise cloudless sky. The temporary condensation of much larger masses of water vapor is necessary in order to be perceptible from a sea-level station. Their presence may be accentuated by looking through a sage green or yellowish green glass.

Owing to the presence of trees that shadowed the laboratory at the noon hour and part of the afternoon in the winter, the observations at Washington are incomplete. However, since there is but little change in air mass at the noon hour in winter, no attempt was made to change the observing station during this investigation.

III. REDUCTION OF DATA

Using this method of making the measurements it is an easy matter to determine, in arbitrary units, the amount of biologically active ultra-violet radiation shut out by common window glass, and note the variation in amount with change in season, atmospheric pollution, etc.

TABLE 1.—*Ultra-violet solar radiation intensity, u. v. Q. of wave lengths less than 313 mμ, also the total solar radiation intensity, Q, in g cal./cm²/min., for different air masses, m, at Flagstaff, Ariz. (altitude 7,250 feet), and on the San Francisco Peaks (altitude 10,500 feet)*

[The time is Mountain Standard (M. S. T.)]

Date	Air mass	Q	Screen transmission		1.000 minus column 4/column 5	u. v. Q	Remarks
			$\frac{a}{I_o}$	$\frac{a+b}{a}$			
1	2	3	4	5	6	7	8
1929		*g cal./cm²/min.*				*g cal./cm²/min.*	
Sept. 1:	*m*						
9 a. m.	1.81	1.28	0.857	0.893	0.040	0.000591	Sky clear over entire hemisphere. Aqueous vapor=8.2 mm.
10.35 a. m.	1.28	1.38	.838	.887	.055	.001010	
Sept. 5:							
8.30 a. m.	2.16	1.33	.855	.888	.037	.000511	Sky perfectly clear at 8 a. m. Cirri appearing at 9 a. m. Sky very blue between clouds. Aqueous vapor=8.1; cloudy p. m.
9 a. m.	1.80	1.38	.853	.888	.039	.000622	
10.40 a. m.	1.29	1.52	.842	.884	.047	.000945	

TABLE 1.—*Ultra-violet solar radiation intensity, u. v. Q. of wave lengths less than 313 mμ, also the total solar radiation intensity, Q, in g cal./cm²/min., for different air masses, m, at Flagstaff, Ariz. (altitude 7,250 feet), and on the San Francisco Peaks (altitude 10,500 feet)*—Continued.

Date	Air mass	Q	Screen transmission		1.000 minus column 4/column 5	u. v. Q	Remarks
			$\frac{a}{I_o}$	$\frac{a+b}{a}$			
1	2	3	4	5	6	7	8
1929		*g cal./cm²/min.*				*g cal./cm²/min.*	
Sept. 6:	*m*						
11 a. m.	1.25	1.51	0.842	0.887	0.051	0.001038	Cirro-cumulus clouds until 11 a. m., then clear until 2 p. m. and after 4 p. m. Aqueous vapor=6.1 mm.
11.30 a. m.	1.18	1.51	.840	.885	.051	.001057	
12.20 p. m.	1.15	1.51	.835	.883	.055	.001147	
4 p. m.	1.85	1.38	.855	.891	.041	.000644	
4.40 p. m.	2.25	1.25	.873	.891	.020	.000251	
5.15 p. m.	3.12	1.19	.878	(.891)	.015	.000139	
Sept. 7:							
11.40 a. m.	1.19	1.55	.838	.883	.051	.001078	Fleeting cirri at 11.30 a. m. Sky cloudless in p. m. but thick white haze on western horizon at 5 p. m. Aqueous vapor=4.4 mm at 5 p. m.
1.40 p. m.	1.21	1.54	.836	.880	.050	.001050	
4.35 p. m.	2.24	1.28	.863	.885	.025	.000322	
5 p. m.	2.60	1.24	.873	(.885)	.013	.000147	
Sept. 9:							
8 a. m.	2.81	1.26	.883	.894	.012	.000130	NE. wind from the Colorado Desert produces "poor seeing." Aqueous vapor=5.0 mm at 9.15 a. m. At 12.17 p. m. clouds and smoke from sawmill cause low value. Cirro-stratus over whole sky at 1.30 p. m.
8.07 a. m.	2.60	1.27	.872	(.893)	.024	.000278	
8.20 a. m.	2.30	1.32	.870	.892	.025	.000329	
8.30 a. m.	2.20	1.35	.863	(.890)	.030	.000414	
9.30 a. m.	1.63	1.43	.855	.884	.033	.000572	
10 a. m.	1.48	1.46	.847	.883	.041	.000756	
11 a. m.	1.27	1.54	.841	(.883)	.047	.000969	
12.01 p. m.	1.18	1.53	.839	.883	.050	.001050	
Sept. 10:							
9.45 a. m.	1.55	1.44	.852	(.888)	.041	.000731	Slight bluish smoke from sawmill at 10 a. m. Large cirro-cumulus clouds before 9 and after 11 a. m. Aqueous vapor=5.0 mm.
10.15 a. m.	1.41	1.47	.847	.888	.046	.000872	
11.15 a. m.	1.24	1.53	.837	.882	.051	.001051	
Sept. 12:							
1 p. m.	1.20	1.60	.837	.880	.049	.001115	San Francisco Peaks. Cloud wisps and more hazy at 1.30 p. m. Large cloud shadow 1.40 to 3.10 p. m.
1.20 p. m.	1.22	1.57	.840	.882	.048	.001066	
3.35 p. m.	1.67	1.46	.853	(.890)	.041	.000756	
3.45 p. m.	1.80	1.44	.867	.893	.029	.000514	
4.05 p. m.	1.93	1.38	.863	.892	.032	.000525	
4.25 p. m.	2.25	1.36	.873	(.892)	.021	.000316	
Sept. 13:							
9.30 a. m.	1.67	1.42	.845	.889	.050	.000850	Sky cloudless all day, but hazy from brush fire 8 to 9 a. m. Smoke from mill at 9.55 a. m. After 11 a. m. sky is clear, blue, no coronal scattering around sun. Aqueous vapor=4.2 mm at 10 a. m., and 3.7 mm at 5 p. m.
9.55 a. m.	1.51	1.45	.845	.883	.043	.000783	
11.10 a. m.	1.27	1.55	.834	.880	.052	.001079	
12.20 p. m.	1.20	1.54	.838	.881	.049	.001029	
2.10 p. m.	1.28	1.48	.839	.881	.047	.000926	
2.45 p. m.	1.43	1.47	.840	.879	.045	.000847	
4.35 p. m.	2.28	1.31	.871	(.889)	.020	.000261	
4.50 p. m.	2.69	1.26	.878	.889	.012	.000133	
Sept. 14:							
11.30 a. m.	1.23	1.64	.837	.871	.039	.000899	San Francisco Peaks. Cloudless; sky bluer, less corona than on Sept. 12. Faint clouds appeared at 1.30 p. m., later 50 per cent cloudy. Aqueous vapor=4.5 mm at 7,250 feet.
12.05 a. m.	1.21	1.63	.837	.878	.047	.001083	
12.25 a. m.	1.20	1.63	.833	.873	.046	.001067	
12.45 a. m.	1.19	1.62	.834	.878	.050	.001152	
Sept. 16:							In forenoon, strong wind from NE., smoky, bluish haze, probably from Colorado desert. Sky cloudless. In afternoon, less wind, sky cloudless; less blue haze on San Francisco Peaks. After 5 p. m. thick whitish haze in SE. and by 6.30 p. m. sky is overcast with thin cirrus clouds. Aqueous vapor=4.0 mm at 8.30 a. m.
9.50 a. m.	1.57	1.36	.850	.883	.037	.000619	
11.45 a. m.	1.22	1.47	.841	.880	.044	.000877	
12.15 p. m.	1.20	1.47	.843	.882	.044	.000882	
2 p. m.	1.30	1.44	.850	.882	.036	.000686	
2.15 p. m.	1.35	1.43	.850	(.882)	.036	.000672	
4.35 p. m.	2.40	1.26	.870	.888	.020	.000242	
4.45 p. m.	2.61	1.23	.878	.892	.015	.000168	
Sept. 19:							At 9 to 9.30 sun shines through thick haze; then distinct cirrus clouds appear. At noon sky is deep blue with large fleeting cirro-cumulus clouds. At 2.30 p. m. sky contains cloud wisps. Aqueous vapor=10.5 mm at 12.30 p. m.
9.30 a. m.	1.72	1.22	.857	.890	.037	.000533	
12.01 p. m.	1.22	1.44	.834	.883	.055	.001073	
12.15 p. m.	1.23	1.44	.833	.881	.055	.001073	
2.35 p. m.	1.40	1.36	.833	.886	.059	.001034	

TABLE 2.—*Ultra-violet solar radiation intensity, u. v. Q, of wave lengths less than 313 mμ, also the total solar radiation intensity, Q, in g cal./cm²/min., for different air masses, m, at Washington, D. C. (altitude 350 feet.)*

[The time is eastern standard (E. S. T.). In column 5 the interpolated values are in parentheses]

Date	Air mass	Q	Screen transmission		1.000 minus column 4/column 5	u. v. Q	Remarks
			$\frac{a}{I_o}$	$\frac{a+b}{a}$			
1	2	3	4	5	6	7	8
1929		g cal./cm²/min.				g cal./cm²/min.	
Oct. 8:	m						
9 a. m.	2.01	0.92	0.880	0.898	0.021	0.000175	Sky cloudless all day. Low stratum of blue haze at 8 to 10 a. m.
9.15 a. m.	1.94	.99	.865	(.893)	.031	.000285	
10 a. m.	1.53	1.15	.863	.893	.028	.000350	
11 a. m.	1.46	1.24	.863	.895	.036	.000504	
12 a. m.	1.41	1.28	.861	(.894)	.037	.000547	
Oct. 9:							
9 a. m.	2.02	.69	.883	(.895)	.013	.000080	Morning clear. Clouds between 9.30 and 11 a. m. Thick haze at noon.
9.15 a. m.	1.96	.78	.880	(.895)	.017	.000123	
12.01 p. m.	1.43	1.11	.884	.902	.020	.000253	
Oct. 18:							
10.15 a. m.	1.73	1.27	.863	.898	.039	.000502	Clear. Cloudless after frost.
11 a. m.	1.54	1.30	.858	(.895)	.041	.000575	
12.01 p. m.	1.48	1.35	.863	.893	.033	.000496	
2.35 p. m.	2.00	1.12	.867	(.893)	.029	.000294	
3 p. m.	2.40	1.02	.870	(.895)	.028	.000220	
3.20 p. m.	2.60	1.00	.880	(.895)	.017	.000120	
3.35 p. m.	3.00	.92	.888	(.898)	.011	.000058	
Oct. 19:							
11 a. m.	1.80	1.10	.869	(.895)	.027	.000291	Clear, cloudless, humid.
11.45 a. m.	1.50	1.14	.875	(.895)	.023	.000290	
Oct. 23:							
9.30 a. m.	2.00	1.19	.875	.893	.021	.000226	Sky clear after rain. "City haze" in southeast at 9 to 10 a. m.
10 a. m.	1.95	1.29	.863	(.893)	.034	.000407	
10.40 a. m.	1.83	1.31	.864	(.893)	.033	.000420	
Nov. 30:							
10.15 a. m.	2.38	1.22	.879	(.900)	.023	.000219	Sky "good." Temperature 16° F.
10.45 a. m.	2.27	1.23	.873	.903	.033	.000329	
Dec. 3:							
10.20 a. m.	2.40	.96	.888	.901	.015	.000111	Sky "poor." Temperature 27° F. windy, sleet on trees.
10.55 a. m.	2.34	.97	.885	(.901)	.018	.000137	
Dec. 20:							
9.50 a. m.	2.97	1.15	.882	(.898)	.018	.000120	Sky clear. Temperature 25° F. at 10 a. m. Ground covered with snow. Sky radiation 6.3 per cent at 10.45 a. m.
10.25 a. m.	2.49	1.24	.883	.898	.017	.000155	
10.55 a. m.	2.37	1.27	.881	(.898)	.019	.000188	
Dec. 21:							
9.45 a. m.	3.00	1.17	.890	(.898)	.009	.000060	Sky cloudless, snow on ground. Temperature 25° F. at 10 a. m. Sky radiation 6.5 per cent at 11 a. m.
10.20 a. m.	2.48	1.22	.883	.898	.017	.000155	
10.40 a. m.	2.40	1.25	.883	(.898)	.017	.000164	
1930							
Jan. 4:							
10.20 a. m.	2.49	1.30	.886	.897	.012	.000115	Sky cloudless, light wind. Temperature 34° F. at 10.30 a. m.
10.50 a. m.	2.44	1.36	.881	(.897)	.017	.000174	
Jan. 6:							
9.40 a. m.	3.06	1.12	.887	(.898)	.012	.000074	Frosty morning. Sky cloudless in a. m. Temperature 40° F. at 10.30 a. m. Sky radiation 7.2 per cent at 10.45 a. m.
10 a. m.	2.80	1.16	.892	.898	.007	.000052	
10.30 a. m.	2.47	1.18	.878	(.896)	.020	.000176	
10.55 a. m.	2.40	1.20	.873	.894	.024	.000222	
11.15 a. m.	2.34	1.21	.864	(.894)	.033	.000314	
Feb. 10:							
10.15 a. m.	2.05	1.346	.871	(.895)	.027	.000322	Morning sky cloudless. Faint cirrus at 11.15 a. m. Sky radiation 7.6 per cent at 11 a. m.
10.30 a. m.	1.99	1.355	.865	.895	.033	.000404	
10.45 a. m.	1.94	1.358	.863	(.895)	.036	.000454	
11.30 a. m.	1.75	1.366	.865	(.895)	.034	.000466	
Mar. 13:							
9.05 a. m.	2.16	.978	.887	.899	.013	.000109	Sky cloudless, more hazy at 11.50. Very hazy in p. m. Sky radiation 10.2 per cent at 11 a. m.
9.25 a. m.	1.87	1.002	.873	(.896)	.026	.000249	
9.55 a. m.	1.64	1.043	.873	(.896)	.026	.000281	
10.45 a. m.	1.48	1.144	.869	.893	.027	.000344	
11.50 a. m.	1.36	1.151	.869	(.893)	.027	.000367	
Mar. 15:							
9.25 a. m.	1.84	1.054	.871	(.895)	.027	.000274	Sky cloudless in a. m.
10.05 a. m.	1.59	1.131	.871	(.895)	.027	.000324	
10.25 a. m.	1.51	1.153	.861	.894	.037	.000471	
11.25 a. m.	1.36	1.198	.861	(.894)	.037	.000523	Sky radiation 10.8 per cent at 11.15 a. m.
11.55 a. m.	1.33	1.207	.860	(.894)	.038	.000545	

TABLE 2.—*Ultra-violet solar radiation intensity, u. v. Q, of wave lengths less than 313 mμ, also the total solar radiation intensity, Q, in g. cal./min./cm² for different air masses, m, at Washington, D. C. (altitude 350 feet)*—Continued

Date	Air mass	Q	Screen transmission $\frac{a}{I_0}$	Screen transmission $\frac{a+b}{a}$	1.000 minus column 4/column 5	u. v. Q	Remarks
1	2	3	4	5	6	7	8
1929		g cal./cm²/min.				g cal./cm²/min.	
Mar. 20:	m						
9.05 a. m.	2.00	1.104	0.869	(0.896)	0.030	0.000299	Sky cloudless in a. m. Sky radiation 7.6 per cent at 11.50 a. m.
10 a. m.	1.58	1.224	.865	.896	.035	.000459	
10.35 a. m.	1.48	1.242	.857	(.895)	.043	.000595	
11.35 a. m.	1.37	1.274	.859	(.895)	.040	.000597	
11.55 a. m.	1.31	1.281	.853	.893	.045	.000690	
Apr. 11:							
10.15 a. m.	1.31	.87	.881	.897	.028	.000292	Thick haze with cirri at 10.40 a. m. to 12.15 p. m. Temperature 75° F. Sky radiation 17.0 per cent at 10.30 a. m.
12.20 p. m.	1.20	.90	.869	(.897)	.031	.000346	
2.45 p. m.	1.58	.64	.881	(.897)	.028	.000192	
Apr. 12:							
9.20 a. m.	1.55	.52	.885	.902	.019	.000107	Thick haze; forest fires on Apr. 11 and 12. Sky radiation 19.0 per cent at 1.05 p. m.
10 a. m.	1.35	.74	.874	(.900)	.029	.000253	
1.15 p. m.	1.24	.78	.875	.898	.026	.000246	
May 3:							
9.05 a. m.	1.42	1.29	.850	.887	.042	.000622	Sky cloudless; clearer in p. m. Sky radiation 8.8 per cent at 9.35 a. m.; 8.2 per cent at 10.55 a. m.
10.05 a. m.	1.36	1.30	.845	(.887)	.047	.000721	
11.05 a. m.	1.24	1.31	.841	.889	.054	.000858	
12.05 p. m.	1.20	1.32	.843	(.889)	.052	.000850	
1.40 p. m.	1.29	1.30	.849	(.890)	.043	.000716	
2.20 p. m.	1.36	1.29	.855	.890	.039	.000594	
May 5:							
9.15 a. m.	1.40	1.05	.875	.893	.020	.000243	Sky thick, hazy; forest fires. Sky radiation 11.6 per cent at 10.30 a. m. More hazy than May 3.
9.45 a. m.	1.37	1.13	.876	(.893)	.019	.000252	
10.40 a. m.	1.26	1.18	.863	(.893)	.034	.000487	
11.55 a. m.	1.20	1.20	.859	(.893)	.038	.000565	
May 10:							
9.15 a. m.	1.38	1.12	.860	(.892)	.036	.000469	Sky cloudless all day. Light SE. wind. Sky radiation 9.2 per cent at 10.35 a. m.; sky radiation to WSW. 1.9 per cent; zenith, 3.3 per cent at 10.50 a. m., to SE. 2.6 per cent at 3.15 p. m.
10 a. m.	1.34	1.20	.860	.892	.036	.000510	
10.55 a. m.	1.23	1.23	.848	(.892)	.049	.000736	
12.02 p. m.	1.19	1.27	.846	.886	.045	.000708	
12.20 p. m.	1.20	1.26	.847	(.886)	.044	.000687	
1.50 p. m.	1.33	1.26	.850	(.883)	.037	.000554	
2.25 p. m.	1.36	1.25	.855	.883	.032	.000472	
June 2:							
9.30 a. m.	1.25	1.22	.858	(.890)	.036	.000533	Sky cloudless in a. m. Sky radiation 7.5 per cent at 10.30 and 7.8 per cent at 11.30 a. m. Sky SW. 2.8 per cent (altitude 40°). Ratio $a \div I_0$ for SW. sky=0.78 to 0.81 showing greater amount of ultra-violet. Thick cirri at 2.10 p. m.
9.55 a. m.	1.18	1.32	.853	.890	.042	.000691	
12.10 p. m.	1.05	1.30	.845	(.890)	.051	.000871	
2.05 p. m.	1.13	1.28	.852	(.890)	.043	.000700	
June 3:							
9.55 a. m.	1.24	1.27	.855	(.887)	.036	.000555	Sky cloudless. Temperature 86° F. at noon. Sky radiation 8.1 per cent at 11.45 a. m.
10.15 a. m.	1.11	1.33	.850	.887	.042	.000720	
11.10 a. m.	1.07	1.35	.847	(.887)	.045	.000794	
12.01 p. m.	1.05	1.37	.845	.887	.047	.000835	
1.30 p. m.	1.10	1.32	.849	(.887)	.043	.000731	
July 7:							
9.45 a. m.	1.40	1.19	.853	.884	.035	.000481	Sky cloudless after heavy rain.
10.30 a. m.	1.21	1.23	.844	(.884)	.045	.000686	
July 19:							
9.10 a. m.	1.42	1.06	.870	.893	.026	.000316	Fine cirri SE. of sun. Sky radiation 10.1 per cent at 10.45 a. m.
10.20 a. m.	1.25	1.14	.850	.890	.045	.000623	
10.35 a. m.	1.22	1.19	.850	.887	.042	.000615	
July 21:							
10.35 a. m.	1.23	1.09	.857	.892	.039	.000519	Sky hazy. Hot, 100° F. Sky radiation 16.5 per cent at 10.50 a. m.
11.00 a. m.	1.17	1.13	.859	(.892)	.037	.000525	
11.40 a. m.	1.10	1.16	.861	(.892)	.035	.000523	
July 25:							
10.35 a. m.	1.24	1.17	.850	(.890)	.045	.000639	Sky clear; hot, 98° F. at noon. Sky radiation 8.3 per cent at 11 a. m.
10.50 a. m.	1.17	1.21	.852	.890	.043	.000653	
11.45 a. m.	1.09	1.23	.844	(.890)	.052	.000825	
Aug. 12:							
9.20 a. m.	1.40	1.22	.857	.886	.033	.000465	Forenoon sky cloudless. Thick haze in west and south horizon at noon. Cool, 72° F. at noon. Sky radiation 7 per cent at 11 a. m.
9.35 a. m.	1.38	1.23	.852	(.886)	.038	.000544	
10.20 a. m.	1.21	1.27	.846	(.885)	.045	.000708	
11.05 a. m.	1.14	1.27	.842	.890	.054	.000866	
11.30 a. m.	1.11	1.28	.854	(.890)	.041	.000676	
11.58 a. m.	1.10	1.28	.851	(.890)	.044	.000726	

The difficulty arises in expressing these relative values in absolute units of energy. No screen or filter is available that has a sharply defined cut-off at a definite wave length. The effective cut-off of one screen that is opaque to wave lengths less than 310 mμ (for example, the barium flint screens used in this work, which has the sharpest cut-off yet found) ranges from about 338 mμ for air mass, $m=1$ to 341 mμ for $m=3$. This, of course, was known at the beginning of the investigation and recently it has been discussed in print (3).

Owing to the fact that the effective cut-off does not coincide with the long wave-length limit (about 313 mμ) of the biologically active ultra-violet radiation, the observed values (in per cent of the total in column 6 of Tables 1 and 2) obtained by this exclusion method of radiometry, are larger than the true values. The difference between these two values could be determined from a knowledge of the solar spectral energy curve using only one filter. Unfortunately, the ultra-violet spectral energy curve, even for average atmospheric conditions is not well known, and in the spectral region of wave lengths less than 313 mμ it is in greater doubt than for wave lengths 313 to about 365 mμ (the latter value being the long wave length limit concerned in the barium flint screen measurement).

In order to obviate these difficulties to some extent, measurements were made with one (a) and with two, ($a+b$) filters of barium flint glass interposed; the latter to determine the percentage of radiation of wave lengths longer than 313 mμ transmitted by the first glass.

As will be noted presently. for the sea-level station, there is a reasonably close agreement between the observed and the computed transmissions. (See fig. 3.) For the higher elevations there is considerable divergence between the calculated and the observed transmissions. (See fig. 4.)

Another difficulty in evaluating the ultra-violet component of solar radiation at 295 to 313 mμ, based upon calculations using the spectral energy curve of the sun, is owing to the fact that, in all such calculations, a smooth energy curve is used, whereas the observed curve is deeply indented by absorption bands. Moreover, the spectral energy curve in the ultra-violet, especially of wave lengths less than 313 mμ is greatly affected by slight changes in atmospheric pollution. This is well illustrated in the transmission measurements of solar radiation through one filter of barium flint glass, which values vary greatly from day to day (as compared with the transmissions of the second filter) for solar radiation of wave lengths longer than 313 mμ that has passed through the first filter, which values vary but little with change in air mass and atmospheric pollution. Hence, as already indicated, the second filter is useful not only in measuring the ultra-violet energy between 313 mμ and about 365 mμ; but, since the ultra-violet cut-off is not sharply defined, it is useful also in obtaining a factor for eliminating the amount of ultra-violet of wave lengths longer than 313 mμ included in the measurement of the ultra-violet of wave lengths less than 313 mμ, obtained with the single filter. This fact, as already stated, was recognized from the start, but the complete correction was not included in the previous paper (2) where only the upper limiting value of the ultra-violet (in per cent of the total) was derived.

The solar spectral energy curves used in the present calculations of the Washington data were taken from the Smithsonian Physical Tables, supplemented in the extreme ultra-violet by the data pub-

lished by O'Brien, by Fabry, and Buisson (4) and by Greider and Downs (5).

The manner of obtaining the ultra-violet radiation of wave lengths less than 313 mμ, by means of this 2-screen method, is illustrated in Figure 2 in which curve A is the observed solar spectral energy curve ($m=1$); curve B gives the spectral energy distribution, I_0, after passing through the Corning glass filter, G986A; curve C shows the spectral energy distribution after transmission through one plate of barium flint glass (G669,a) and curve D shows the spectral energy distribution after passing through the two filters (G669,$a+b$).

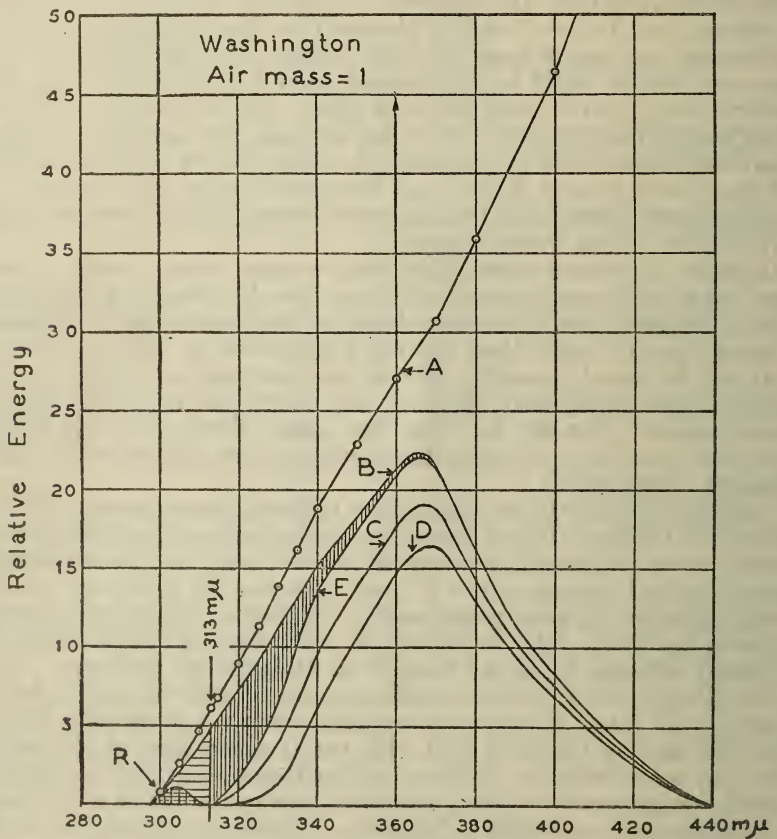

FIGURE 2.—*Graphical method used in reducing the data*

The whole shaded area between curves B and E represents the ultra-violet spectral energy (column 6 in Tables 1 and 2) excluded by this 2-screen method of making the measurement, whereas, the horizontally shaded area, of wave lengths less than 313 mμ, represents the ultra-violet energy that it is desired to evaluate. Incidentally, it may be noted that the effective wave length cut-off, using two screens, occurs at about 329 mμ for air mass $m=1$ to 330.5 mμ for $m=3$. It is the sharpest cut-off of all the screens yet tested.

For the sea-level station (Washington, altitude=350 feet) the calculated per cent transmissions for the single barium flint screen,

indicated by the symbol a/I_0, and for the two screens, symbol $(a+b)/a$ (fig. 3) are in as close agreement as can be expected. The ratios of observed and calculated values $[a/I_0 : (a+b)/a]$ are in much closer agreement. In view of this close agreement between the calculated and the observed data, it is assumed permissible to calculate suitable factors, F, from the average spectral energy curves, in order to reduce the observed measurements (given in column 6 of Tables 1 and 2) represented by the whole shaded area between curves B and E, to the energy represented by the horizontally shaded area comprised of wave lengths less than 313 mμ (shown in fig. 2) which energy, as just mentioned, it is desired to evaluate.

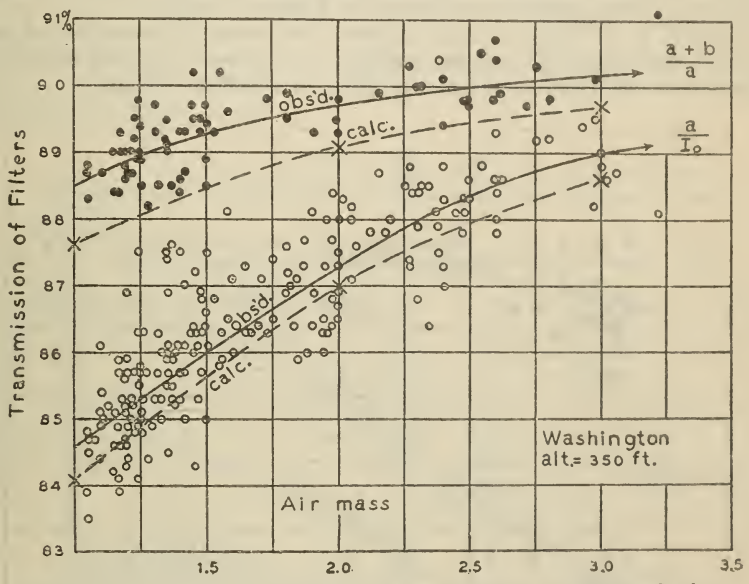

FIGURE 3.—*Observed and calculated transmissions of one and of two standard barium flint glass filters, for different air masses, at Washington, September, 1929, to January, 1931*

These factors, F, are obtained graphically from the average solar spectral energy curves, for air masses $m=1$, 2, and 3, in which the area, I_0, represents the radiation measured after transmission through the combined filter consisting of the water cell and the purple glass screen, G986A. Similar curves were obtained to represent the spectral transmissions a/I_0 and $(a+b)/a$, after insertion of the barium flint screens a, and $a+b$. The ultra-violet ends of these curves representing I_0, a/I_0 and $(a+b)/a$ are shown in curves B, C, and D in Figure 2.

Since these screens have no selective absorption in the infra-red (which is terminated at 1.4 μ by the water cell) the determination of the reduction factors, F, involves an accurate integration of only the ultra-violet areas of the curves B, C, D, and E, and of the shaded area of wave lengths less than 313 mμ, depicted in Figure 2.

These correction factors, F, for different air masses are shown graphically in Figure 5, from which curve is taken the value for the particular air mass through which the measurements were made.

The observed amount of ultra-violet shut out by the barium flint glass screens (given in column 6 of Tables 1 and 2; these values are 1.000 − columns 4 ÷ 5) is multiplied by the corresponding factor, F (fig. 5), corresponding with the air mass, m, given in column 2 of Tables 1 and 2, in order to obtain the amount of ultra-violet comprised in the band of wave lengths less than 313 mμ.

Since all these values are in terms of the total incident solar radiation intensity, Q (g cal./cm^2/min.) and of the transmission factor K (=0.0837) of the combined water cell and glass screen, G986A, the component ultra-violet solar radiation, *u. v. Q.*, of wave lengths less than 313 mμ is the product of $K.Q.F$ and of the values of the ultra-violet part of Q, given in column 6 of Tables 1 and 2.

Column 7 of Tables 1 and 2 gives the total ultra-violet of wave lengths less than 313 mμ, in sunlight, as deduced by this method of observation and reduction of the data to absolute values.

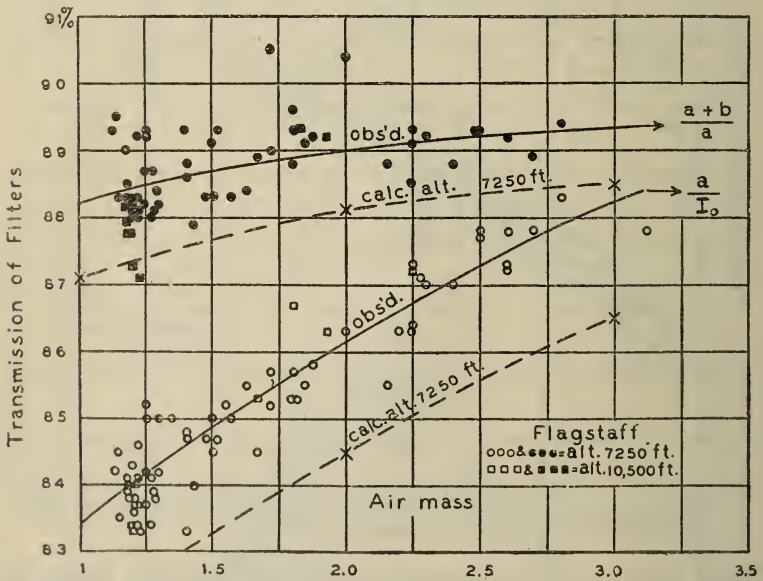

FIGURE 4.—*Observed and calculated transmissions of barium flint glass filters for different air masses, at Flagstaff, Ariz., August to September, 1929*

In view of the great fluctuations in the ultra-violet component from day to day (see figs. 3 and 4), the logical procedure would be to use correction factors, F, representing these extremes. However, since the corresponding spectral energy curves are not known it seems sufficient to use the average solar spectral energy curve.

As shown in Figure 4 the values of a/I_0 and of $(a+b)/a$, calculated for high elevations, are much lower than the observed values. The ratios of these two measurements are in still greater disagreement with the observed values, indicating that the solar spectral energy curves, used in the calculations, are richer in short wave length ultra-violet radiation than obtains during actual observations. This is entirely different from the conditions at sea level where the observed and the calculated ratios $(a/I_0 : (a+b)/a)$ are in fairly good agreement.

The factors, F, for reducing the Flagstaff observations to value for the spectral band of wave lengths less than 313 mμ were, therefore, obtained in the following manner. Instead of air masses the equivalent pressures, in millimeters of mercury (see fig. 5), were plotted against the correction factors, F, calculated for Washington (pressure = 760 mm). From this curve were read the correction factors for the two Flagstaff stations (pressures 580 and 500 mm, respectively) for air masses, $m = 1$, 2, and 3.

In view of the fact that the total solar radiation intensity, Q, obtained by meteorologists, is in g cal./cm²/min., the present data are given in this unit. The custom among physicists and physiologists is to evaluate thermal radiation flux in radiant power, usually in milliwatts or microwatts (μw) per cm². The data in Tables 1 and 2 may be reduced to watts per cm² by applying the approximate factor 0.07 (= 4.18 ÷ 60). They are given in gram-calories and in microwatts in the illustrations.

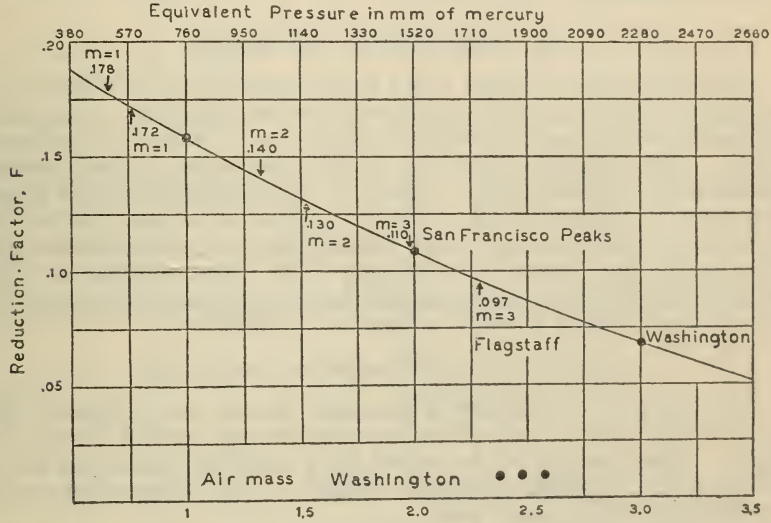

FIGURE 5.—*Reduction factors used in determining the ultra-violet radiation of wave lengths less than 313 mμ*

The data given in column 7 of Tables 1 and 2, represent all the ultra-violet solar energy available in the spectral band of wave lengths less than 313 mμ, generally accepted by biologists as having therapeutic properties, especially in preventing and healing rickets. But the biological effectiveness for equal energy, is not the same for all wave lengths, being a maximum at about 297 mμ, and decreasing to an extremely low value at 313 mμ (6). The spectral erythemic response curve, for equal energies, observed by Hausser and Vahle, by Luckiesh, Holladay, and Taylor (7) and by the writers (data unplublished) is a maximum at 297 mμ descreasing to an extremely low value at wave length 313 mμ.

The rubescence curve (R in fig. 2), which is analagous to the luminosity curve of the eye, is the spectral erythemic response curve for an equal energy spectrum multipled by the spectral energy dis-

tribution of the source, which, in this case, is the sun (8). The doubly shaded area under the rubescence curve, R, in Figure 2 represents the spectral effectiveness of ultra-violet solar radiation in producing an erythema. The ratio of the shaded area under the rubescence curve R, relative to the total shaded area of wave lengths less than 313 mμ, at sea level, is the erythemic efficiency. This ratio does not seem to vary greatly with air mass, the calculated values being 14.5, 14.0, and 12.8 per cent, respectively, for the corresponding air masses, $m=1$, 2, and 3. In other words, the biologically effective ultra-violet component, R, is about (14 to 13 per cent) one-seventh to one-eighth of the total ultra-violet component, *u. v. Q.*, recorded in column 7 of Tables 1 and 2; or a range of about 8 microcalories per cm^2 per minute, for $m=3$ to about 125 microcalories per cm^2 per minute for $m=1.05$. Expressed in terms of radiant power these values are approximately 0.6 and 9 microwatts per cm^2, respectively, showing the extremely small amount of ultra-violet energy useful for thereapeutic purposes that is contained in solar radiation.

IV. DISCUSSION OF DATA

The data given in Tables 1 and 2 when plotted to scale show interesting information, some of which will now be discussed. A complete discussion of the measurements would be too tedious for the general reader. The tabulated data and remarks can be left to the specialists interested in phototherapy. Many of the phenomena have already been noted by others, but not always recorded on a quantitative basis. Since the present data are based upon measurements that were made only during the clearest, cloud-free weather, the averages are necessarily higher than the values that are based upon measurements which are obtained during all sorts of weather conditions.

1. EFFECT OF ATMOSPHERIC POLLUTION

By atmospheric pollution is generally meant the temporary presence of dust, smoke, etc. The dust may be transported from an arid region. The smoke may be caused by a neighborhood brush fire, by a forest fire, a passing railroad engine, or the exhaust gases from automobiles, "city haze," etc.

Calculations of the sea-level solar spectral energy curve from data obtained at high elevations seems to indicate the presence of a greater amount of ultra-violet than actually observed, just as though there is a local atmospheric pollution not accounted for in the average spectral energy curve. This, of course, is to be expected.

Notable examples of unusual atmospheric pollution by automobiles, which affected the Washington measurements, are October 8 and 23, 1929, when the transmission of short-wave length ultra-violet solar radiation was doubled in the course of about 15 minutes. (See Table 2.) The low value of the total solar radiation intensity, Q, and of the ultra-violet component, *u. v. Q.*, observed on October 9, 1929, are equally interesting.

At the Lowell Observatory station on several occasions the measurements were interrupted by smoke from wood that was burned in a sawmill some miles away. The interesting part of the phenomenon was that on one occasion the blue color of the smoke so closely matched the intensely blue color of the sky that, in the bright sunshine, its presence could hardly be distinguished and would have

escaped notice if its had not affected the thermopile readings. (See Table 1, measurements of 9.55 a. m., Sept. 13, 1929.)

The great variation in the ultra-violet component of solar radiation, as a result of variations in sky conditions, are shown in the high altitude observations (fig. 6) and to a greater extent in the observations at Washington. (Fig. 7.) At the latter station, on some days, the ultra-violet component for air mass, $m=1.5$, is not much larger than in the morning and late afternoon of the clearest days, air mass, $m=3$.

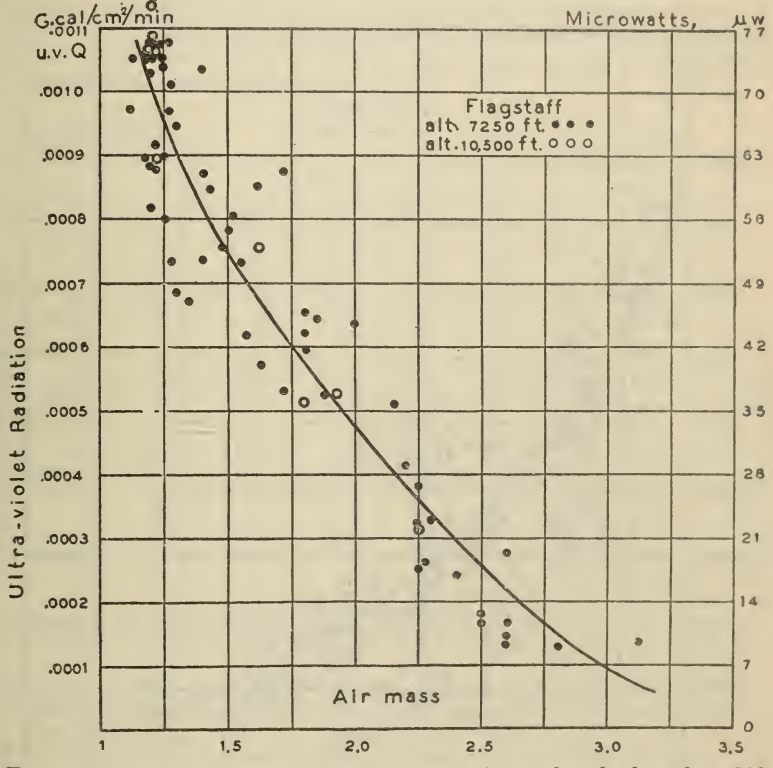

FIGURE 6.—*Total ultra-violet solar radiation of wave lengths less than 313 mμ, in g cal. per cm² per min. (also in microwatts, μw, per cm²), for different air masses at Flagstaff, August and September, 1929*

As is to be expected, for a given air mass, the greater the amount of scattering of the incident rays, the smaller the amount of the directly incident ultra-violet solar radiation, *u. v. Q.* This is illustrated in Figure 8 ($m=1.25$) in which is plotted the total ultra-violet component, *u. v. Q.*, against the per cent of (scattered) "sky radiation," present in the total incident ultra-violet solar radiation measured.

2. EFFECT OF ALTITUDE

The effect of altitude on the short-wave length ultra-violet component of sunlight is well known, though quantitative data are not numerous.

Two outstanding factors contribute to the amount of ultra-violet received. The first factor is that, with rise in elevation, the spectral absorption is decreased and the intensity of the short wave lengths, 300 mμ relative to 320 mμ, is greatly increased. This is indicated in the lower values of the transmission of the barium flint glass screens, a/I_o and $(a+b)/a$, in going from the 7,250 feet elevation to the 10,500 feet elevation.

The second factor is the amount contributed by atmospheric scattering along the path of the incident rays. In this connection Pettit

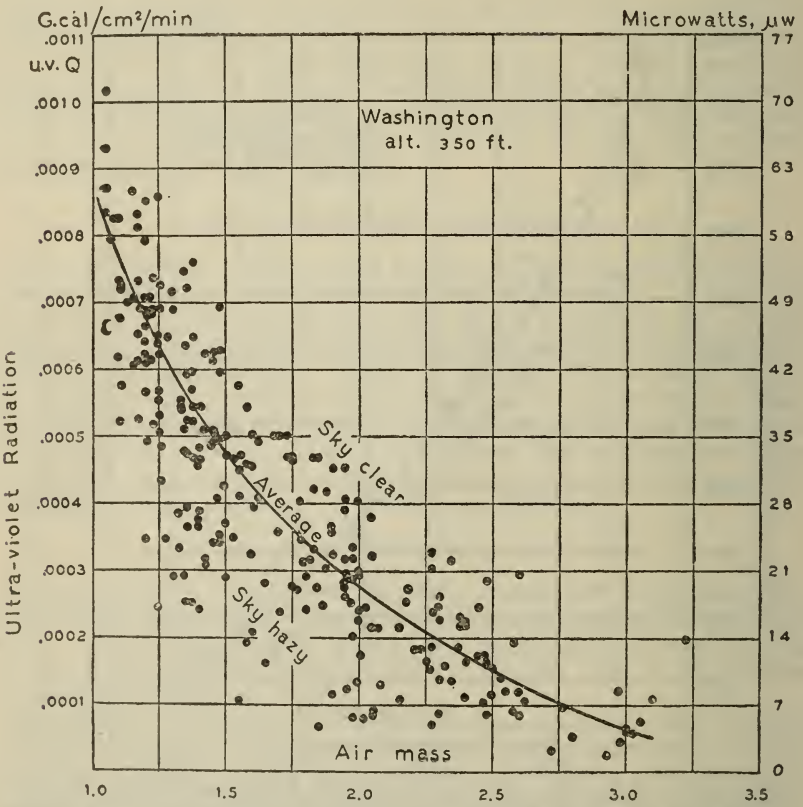

FIGURE 7.—*Total ultra-violet solar radiation, of wave lengths less than 313 mμ, in g cal. per cm² per minute (also in microwatts per cm²), for different air masses at Washington, September, 1929, to January, 1931*

(9) has recently contributed some interesting data, showing that, in going from a sea-level station to a mountain top, the total amount of ultra-violet radiation from the sun increases to some extent, but the ultra-violet scattered by the sky is greatly decreased. His measurements were made at 320 mμ, at which wave length, as shown by the transmission factors $(a+b)/a$, the effect of scattering, with air mass and change in altitude, is less marked than for the shorter wave lengths (at 300 mμ) involved in the present measurements using the single filter, a/I_o.

Using a photo-electric cell covered with a film of silver, which transmits ultra-violet of wave lengths at 320 mμ, Pettit (9) found that about 50 per cent of the ultra-violet observed at an elevation of 845 feet was contributed by the sky, while at an elevation of 5,700 feet only about 30 per cent of the total ultra-violet measured was contributed by the sky. On the other hand, the total ultra-violet (sun plus sky) observed at the 5,700-foot elevation was only about 5 per cent greater than at the lower elevation.

These observations are substantiated by the present measurements (see Table 1 and fig. 9) where the total ultra-violet, for $m = 1.2$, was *u. v. Q.* = 1,150 microcalories at the 10,500-foot elevation as compared with *u. v. Q.* = 1,080 microcalories per cm² per minute at the 7,250-foot elevation, a difference of only about 8 per cent under average conditions at that season, September, 1929.

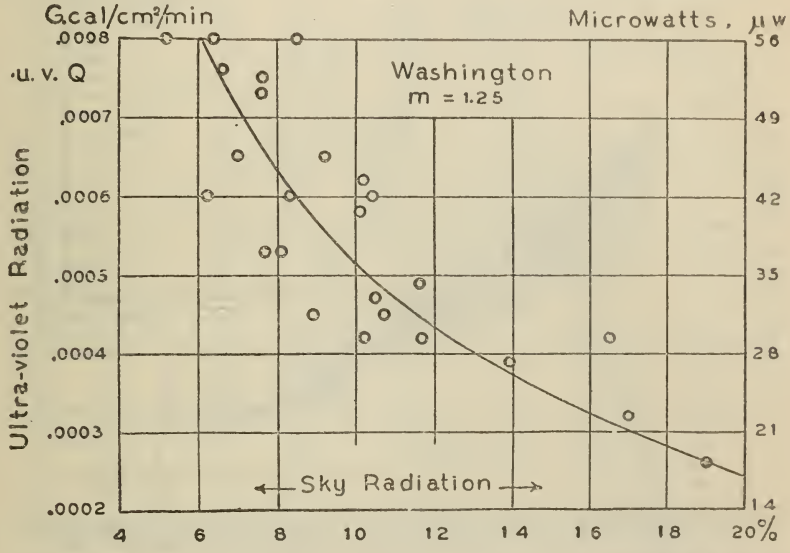

FIGURE 8.—*Percentage of sky radiation present in the total ultra-violet of wave lengths less than 313 mμ, at Washington, for air mass m=1.25. (See fig. 7.)*

The greater erythemic effectiveness of the ultra-violet rays, observed at the higher elevation is therefore to be ascribed to the presence of a greater amount of short wave lengths (at 297 to 302 mμ) ultra-violet radiation, as indicated by the lower transmission, a/I_o observed through the barium flint glass filter.

3. EFFECT OF HUMIDITY ON SCATTERING

But little information is available regarding the amount of scattering caused by water vapor along the path of the incident radiation.

The Washington measurements (Table 2) show that on the clearest days (absence of smoke and dust) only about 5 per cent of the total *u. v. Q.* is scattered sky radiation, the average being about 10 per cent of the total, rising to 19 per cent on April 12, 1930, as a result of the Shenandoah forest fire.

The most interesting results on the effect of humidity were obtained at the Arizona stations, where observations were begun near the close of the rainy season when the pressure of the aqueous vapor at the 7,250-foot elevation was 10 mm. This was followed by a period of low vapor pressure (4 to 5 mm) which, fortunately for a verification of the earlier observations, was terminated by a day (Sept. 19, 1929, Table 1) of relatively high vapor pressure.

As shown in Figure 10, where the total ultra-violet radiation, *u. v. Q.*, is plotted against the total solar radiation intensity, *Q*, during the period of relatively high vapor pressure, the ultra-violet component, *u. v. Q.*, is distinctly higher for a given value of *Q* (group *A*) than during the period of low vapor pressure (group *B*), so that with a solar intensity of $Q = 1.3$ g cal. the average *u. v. Q.* was as high

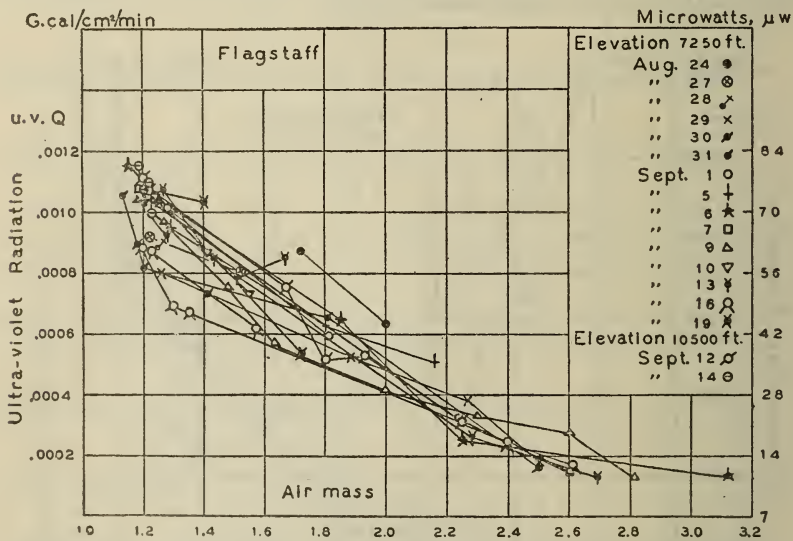

FIGURE 9.—*Daily variation in the total ultra-violet radiation of wave lengths less than 313 mμ, Flagstaff, Ariz., August and September, 1929*

(0.0009 g cal.) as was observed at the low vapor pressures (4 mm) when $Q = 1.5$ g cal. It is to be noted, however, that, while the total ultra-violet component at the 7,250-foot elevation is almost as high as observed at the 10,500-foot elevation, the spectral quality is different, containing a somewhat less amount of the short-wave lengths 290 to 300 mμ. This conclusion follows from the proper interpretation of the transmissions observed with the barium flint glass screens.

It is relevant to add that the effect of humidity upon the total incident solar radiation, *Q*, is well known to meteorologists, the relatively lower values of *Q* in June and July being caused, in part, by the increased amount of water vapor in the atmosphere.

In this connection it is interesting to note the observations of Dannmeyer (17), showing the importance of sky radiation upon the total biologically active ultra-violet incident in high latitudes—Iceland, Finland, Norway, etc. During a period of exceptionally clear weather, at midday, in June and July, the total ultra-violet in direct sunlight in Iceland (measured with a cadmium photo-electric

cell) was never greater than 45 per cent of the *u. v. Q* received from the whole sky. He comments upon the biological effect of this sky radiation upon the natives, living in towns surrounded by basalt walls 400 m high, whose faces, blanched during the long dark winters, show a ruddy hue long before the sun shines directly into the fiords.

4. DAILY VARIATION IN ULTRA-VIOLET RADIATION

The daily variation in intensity of the ultra-violet component, *u. v. Q.*, from an imperceptible amount at sunrise and sunset to a maximum at the noon hour is well known and needs but little comment in the present paper.

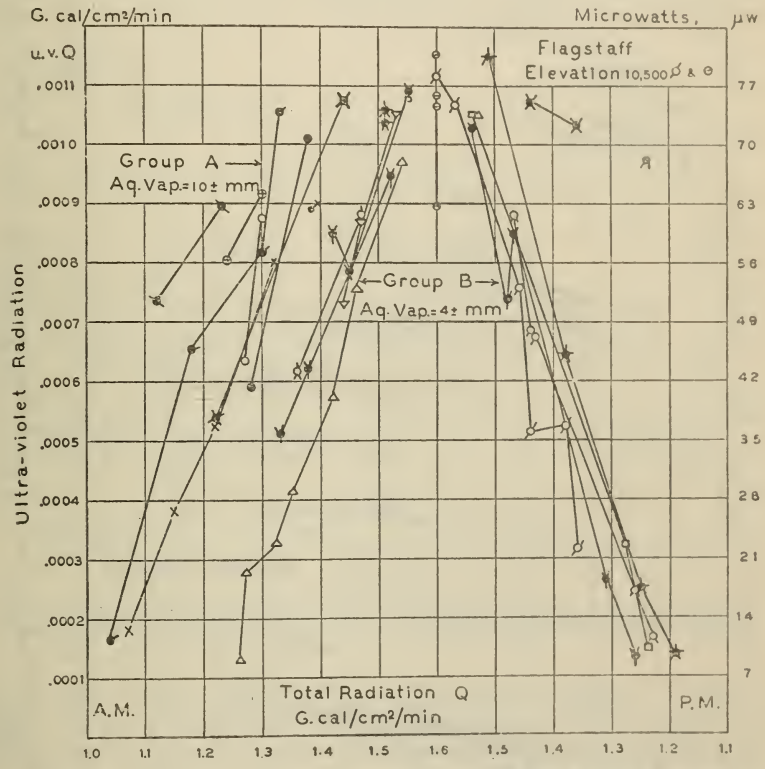

FIGURE 10.—*Daily variation in ultra-violet radiation (u. v. Q) relative to the total incident solar radiation (Q) in g cal. per cm² per minute, at Flagstaff, Ariz., showing the effect of aqueous vapor*

In Figure 10 are depicted some of the measurements of the *u. v. Q.* made at the Flagstaff, Ariz., stations. The Washington measurements (fig. 7), being plotted against air mass, do not distinguish between the forenoon and afternoon observations. However, in both cases, the wide variations in the *u. v. Q.*, throughout the day and on different days, indicate the futility of attempting to specify intensities for average meteorological conditions. Fortunately, common experience shows that the human body is not greatly affected by these variations in intensity, so that a precise dosage meter is not necessary to evaluate the intensities in heliotherapy as now practiced.

5. SEASONAL VARIATION IN ULTRA-VIOLET RADIATION

In Figure 11 are plotted the various observations of ultra-violet radiation, *u. v. Q.* at Washington, for different times of the day (different air masses given at the top of fig. 11) during different

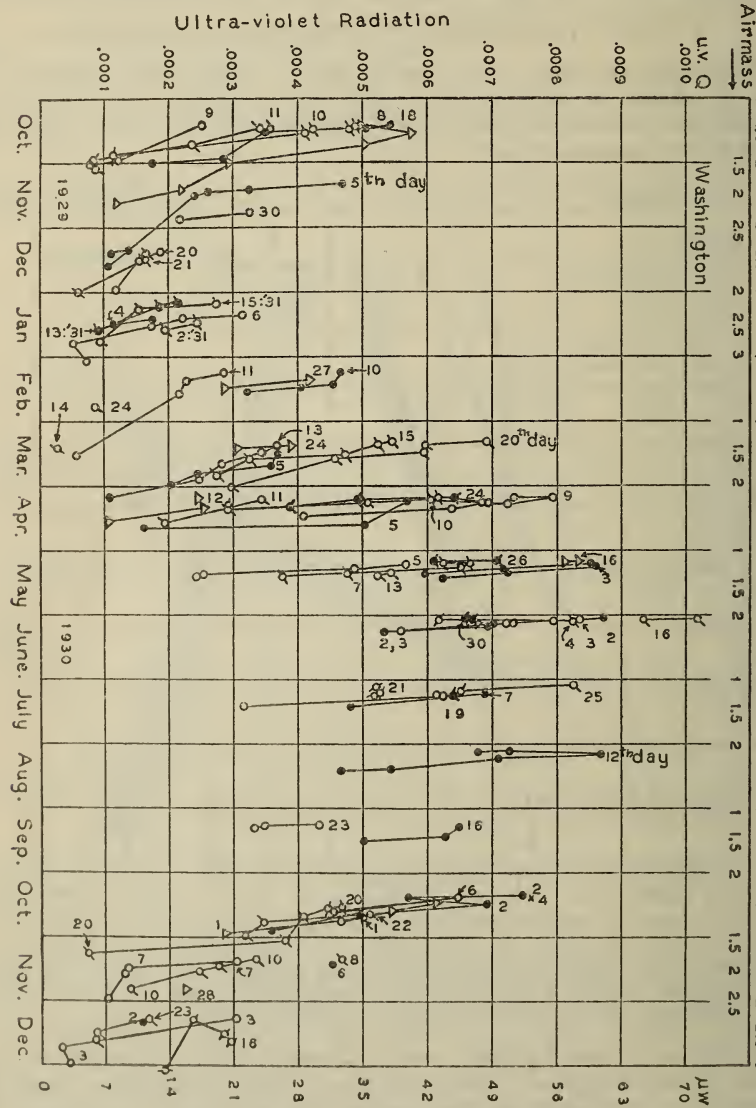

FIGURE 11.—*Daily and seasonal variation in ultra-violet solar radiation of wave lengths less than 313 mμ, in Washington, October, 1929, to December, 1930*

months of the year. The envelope, drawn through the maximum and the minimum values, produces an interesting curve, showing, the well-known periodicity in the intensity, varying from a sharply defined minimum in December to a broadly defined maximum extend-

ing from May to August. No attempt is made to correlate the incident ultra-violet with solar activity (sun spots) which is being investigated by Pettit (9).

In Figure 12 the data are plotted to illustrate the amount of ultra-violet incident at Washington at different hours of the day (usually the forenoon) during the year 1930 and the first part of 1931. The low average values in July are owing to haziness caused by the drought (dust) and forest fires.

As illustrated in Figure 12, the ultra-violet component radiation, *u. v. Q.* of biological importance in sunlight is imperceptibly small before 9 a. m. (and after 3 p. m.) in winter; and only during three to four hours, in the middle of the day does it become of real importance. However, by February, and especially by the beginning of March,

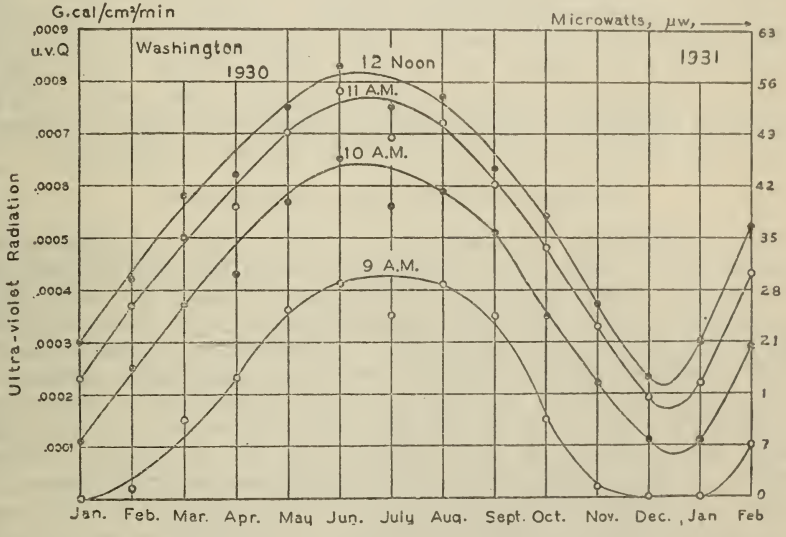

FIGURE 12.—*Average ultra-violet solar radiation intensities of wave lengths less than 313 mμ at the even hours, 9 a. m. to noon on the clearest days throughout the year 1930, in Washington*

the amount of ultra-violet is greatly increased. This is a point that appears to have been overlooked in some of the earlier biological tests which were made in February, and, hence, do not apply to conditions that obtain in December. For even if there are more clear days in December than in January and February, accepting the observations of Russell, Massengale, and Howard (11) that the duration of the effect of a single exposure to ultra-violet radiation upon bone formation in chicks lasts about two weeks, then the biological action obtained on a single clear day in January and February would be far more effective than several days of exposure to the sun, during December.

The foregoing data are interesting in showing that in addition to the daily variation in the intensity of the ultra-violet component, *u. v. Q.*, there is the well-known seasonal variation which is a minimum at the winter solstice, December 22, when at the noon hour on the clearest day, in Washington, the *u. v. Q.* is less than 200 micro-

calories (about 14 μw) per cm^2 or about one-fourth the maximum values at the summer solstice. This value seems to be remarkably high, but it is to be noted that the total amount of ultra-violet, *u.v. Q.*, observed in December is of wave lengths 305 to 313 mμ, especially of the latter wave lengths, which have a low biological action.

If we consider only the energy included under the rubescence curve, *R*, in Figure 2, which equates the spectral energy according to its biological (erythemic) effect, then the maximum biologically active ultra-violet component, *u. v. Q.* calculated from the average solar spectral energy curve, at the winter solstice, is about one-fifth to one-sixth the maximum at the summer solstice.

The biological tests of Tisdall and Brown (10) made at Toronto (latitude 43° 6′), indicate that during the winter months the anti-rachitic effect is about one-eighth as great as in April and May. Assuming the same meteorological conditions at Toronto and at Washington, it is to be noted, however, that in making biological tests the animals must be exposed two to three hours per day, on successive days, for a period of a month, during which time the average *u. v. Q.* especially during the winter months, is much lower than the average of only the clearest days, included in the present investigation.

6. ULTRA-VIOLET IN SKY RADIATION

It is well known that there is a greater amount of ultra-violet, relative to the total, in sky radiation than in the directly incident solar ways. Hence, although the intrinsic brilliancy of a small area of the sky is much lower than direct sunlight, since the area of the sky is 92,000 times that of the sun, the integrated amount of ultra-violet incident from the whole sky can be an appreciable amount.

On page 682 of the previous paper (2) measurements were cited indicating a value of *u. v. Q* = 0.00029 g cal/cm^2/min. for practically the whole north sky on an exceptionally clear day in March. When reduced to the present system of measurement (using the factor, *F*, in fig. 5, in order to obtain the value for wave lengths less than 313 mμ) this value amounts to (approximately) *u. v. Q* = 0.00006 g cal/cm^2/min. or about one-fifteenth of June sunlight, which is an appreciable amount.

By means of a uranium photo-electric cell, sensitive to wave lengths less than 334 mμ and the barium flint glass screen, it was found that, of the total intensity measured in foot candles, the light from the north sky contains about 50 per cent more of the biologically active ultra-violet component than direct sunlight. However, since the intensity of skylight that can pass through an average sized window, and shine upon an object 5 m back of the window, is only 10 to 12 foot candles or about 1/800 to 1/1000 of full sunlight, it follows that it would be necessary to expose an object for 14 to 15 hours to receive the same amount of ultra-violet as would be obtained in a 1-minute exposure to direct June sunlight (12).

7. COMPARISON OF DATA

As already mentioned, practically all the quantitative data, heretofore available, on the biologically active ultra-violet in sunlight, were derived by calculation from an assumed average spectral energy curve (9, 13) which formed also the basis of one method of attack, previously

used by the writers (2). In the present investigation the average solar spectral energy curve is used merely as a secondary factor for reducing to an absolute energy basis the ultra-violet energy measurements obtained under various atmospheric conditions. While the data obtained by these two methods of attacking the problem are in reasonably good agreement, nevertheless the present measurements show that such comparisons can be used only in a general discussion of the problem, and that in accurate, quantitative biological tests, simultaneous local ultra-violet measurements must be made.

From his analysis of the solar spectral energy curve observed on Mount Wilson, supplemented by measurements with a silvered photoelectric cell that has a maximum response at about 320 mμ, Pettit (9) deduced that the intensity of the ultra-violet component of wave lengths 290 to 310 mμ, in midsummer sunlight amounts to about 70 microwatts (μw) per cm². This amounts to about 90 μw per cm² for wave lengths 290 to 313 mμ. The highest values observed in Washington (wave lengths 290 to 313 mμ) are close to 70 μw (0.0010 g cal/min., fig. 7) per cm².

The method of observation used by Grieder and Downs (5) has an element of similarity to the present method in that the per cent of the total incident energy that is located in the ultra-violet and visible spectrum, is determined by means of filter of red glass. It is therefore necessary to observe the spectral energy curve of only the ultra-violet and the visible part of the spectrum by means of a spectropyrheliometer (14) and, by graphical integration, determine the amount of radiation in the band of wave lengths 290 to 310 mμ.

The value of the ultra-violet component, observed by Greider and Downs (5) during the noon hour, at Springfield Lake, Ohio (altitude about 1,200 feet) ranges from 12 μw per cm² in October to 23 μw per cm² in June, or about 16 and 30 μw per cm², respectively, using the long wave length limit at 313 mμ. Deducting about 10 per cent from the herein-recorded measurements for sky radiation, the corresponding Washington measurements are approximately 35 and 50 μw per cm² 0.0005 and 0.00073 g cal. (fig. 12), respectively. Their measurements at Cragmor, Colo. (altitude about 6,500 feet), gave 16 μw per cm² in November to 53 μw per cm² in June, or 21 and 69 μw per cm², respectively, using the long-wave length limit at 313 mμ. Extrapolating the herein-described measurements at Flagstaff, Ariz. (fig. 9), to air mass $m = 1.02$ (June) and deducting 10 per cent for sky radiation gives 77 μw per cm² (0.0011 g cal.).

Supplementing these radiometric measurements are the physiological tests of Luckiesh (15) who, from determinations of minimum perceptible erythema and computations of energy between 280 and 310 mμ produced by a tungsten-filament lamp with a special bulb, concludes that the best midsummer sunlight supplies not less than 25 μw per cm² with a probable value of 40 μw per cm² of ultra-violet energy shorter than 310 mμ, or 33 and 52 μw per cm², respectively, for wave lengths less than 313 mμ.

From the foregoing it appears that the present method of measuring ultra-violet solar radiation gives slightly higher values than the method employed by Greider and Downs, and lower values than obtained by Pettit. The various estimates of the value of ultra-violet solar radiation of wave lengths less than 313 mμ, for mid-latitude sea-level stations, during midday in midsummer, are as follows: Pettit, 90 μw;

Greider and Downs, 33 μw (corrected for sky radiation); Luckiesh, 33 to 52 μw; Coblentz and Stair 55 μw per cm^2 (20).

Considering the variety of methods of attack and of reducing the measurements, and the marked local differences in meteorological conditions at the different stations, these estimates are in as good agreement as can be expected. For, while this general agreement is of interest, the question of primary importance is a quick, reliable, and convenient method of determining, in absolute value, the amount of biologically effective ultra-violet radiation incident at a given station.

Heliotherapists find that the best time of the day to give sunbaths is in the early forenoon (8 to 9 a. m.) and late afternoon in summer, and during the noon hours in winter. From a correlation of their radiometric data with these biological data, Greider and Downs (5) estimate the dosage intensity of "clinical sunlight," used in heliotherapy amounts to about 14 μw per cm^2. On the basis of the present method of observation, which includes wave lengths less than 313 mμ the dosage unit of "clinical sunshine" is about 20 μw per cm^2. This is considerably smaller than the estimate previously published (8, 2). However, the former estimate was based upon an assumed upper limit of 70 μw, which is negatived by the results of the present research (20).

V. SUMMARY AND ACKNOWLEDGMENTS

The present paper is a contribution to the investigation of instruments and methods of radiometry, in particular to the quantitative measurement of the component of ultra-violet solar radiation, of wave lengths less than 313 mμ, which biologists recognize as of especial importance in the prevention and cure of rickets.

The apparatus used consisted of a nonselective radiometer (a thermocouple) permanently covered with a cell of water and glass filter, Corning G986A, which combination is highly transparent to ultra-violet and largely opaque to the visible and the infra-red rays. By temporarily placing a screen of barium flint glass in the path of the incident rays, the ultra-violet of wave lengths less than 313 mμ is evaluated by exclusion from the total ultra-violet measured.

Observations were made at Washington, D. C. (latitude 38.9°; altitude 350 feet) at the Lowell Observatory, Flagstaff, Ariz. (latitude 35.2°; altitude 7,250 feet) and on the San Francisco Peaks, near Flagstaff (altitude 10,500 feet).

Data are presented on the incident ultra-violet solar radiation as affected by (*a*) atmospheric pollution, (*b*) altitude, (*c*) humidity, (*d*) time of the day, (*e*) season of the year, and (*f*) sky radiation.

Among the outstanding items of interest is the great reduction in intensity of ultra-violet radiation by atmospheric pollution by dust, smoke, and the combustion products of automobiles. This produces a wide variation in the daily and seasonal observations, especially at sea-level stations.

At high elevations the spectral quality of the ultra-violet component is richer in the short wave lengths (295 to 305 mμ) than at sea-level; but owing to atmospheric scattering, the total amount of ultra-violet of wave lengths less than 313 mμ, at sea-level on the clearest days, is almost as large as at high altitudes.

Atmospheric water vapor is an important contributing factor in scattering ultra-violet radiation, that is most easily observed with changes in humidity at high altitudes.

The amount of ultra-violet solar radiation of wave length less than 313 mμ, previously estimated to be 0.3 per cent of the total incident radiation, was an upper limiting value which is now superseded by more complete measurements, made on the clearest days in Washington, indicating noon hour values ranging from about 14 microwatts (200 microcalories per minute) per cm^2 in December to about 56 microwatts (800 microcalories per minute) per cm^2 in June (20).

Acknowledgements are due to the Lowell Observatory, in particular Dr. C. O. Lampland, for the facilities placed at our disposal, including transportation to the San Francisco Peaks; also to Mrs. W. W. Coblentz for assistance in making the observations in Arizona, and to J. M. Hogue for assistance in making some of the latest observations in Washington. Acknowledgment is due to Dr. H. H. Kimball, of the United States Weather Bureau, for the calibration of the Angström pyrheliometer used at the Flagstaff stations and to I. F. Hand for the numerous data on air masses (m) and solar intensities (Q) supplied in connection with the Washington measurements of ultra-violet radiation.

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20. A further study of the transmissions of the filters and correction factors indicates that the hereinrecorded values should be increased by, perhaps, 10 to 20 per cent.

Washington, February, 21, 1931.

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